

6.7 Borehole P9-2-7 Survey Results

- Total casing depth is 11.17 ft.
- The waste zone is shallow and extends from 5 ft to the maximum survey depth of 10.87 ft. The maximum concentration of chlorine, Pu-239, and Am-241 occur at or near the maximum survey depth.
- Passive-neutron activity is elevated in the waste zone from 5 to 10 ft with count rates up to 23 c/s. The passive-neutron distribution profile is similar to the Am-241 and Pu-239 distribution at 7 ft but does not respond to the increase in radioactivity at 10 ft. Photo peaks associated with high passive-neutron activity (1275 and 2223 keV) were detected at 7 and 10 ft respectively, and may indicate a different composition of the waste at the two depth locations.
- The hydrogen log increased slightly in the lower portion of the waste (8 to 10 ft). The neutron-moisture log decreased in the waste zone to less than 1 wt% at 7 ft.
- Chlorine was detected over an extended interval from 7 ft and the maximum survey depth of 9.83 ft with a maximum activity of 5.8 c/s at the maximum survey depth. The maximum chlorine activity of the 8 additional borehole discussed in this report occurred in this borehole.
- Americium-241 was detected from 5 ft to the maximum survey depth of 10.87 ft with concentrations up to 230 nCi/g.
- Plutonium-239 was in the same interval as Am-241 (5 to 10.87 ft) and with similar distribution profile. The maximum concentration of 2550 nCi/g is at 10.5 ft.
- Natural radionuclides: Uranium activity increased in the upper portion of the waste zone (6 to 8 ft) with concentrations up to 2.3 pCi/g.
- Silicon and calcium responses decreased in the waste zone (6 to 9 ft).
- Iron and the 1778 keV both decrease (7 to 8.5 ft) and increase (8.5 to 10 ft) in the waste zone and at slightly different depth locations as has been characteristic of the Pit 9 study area.

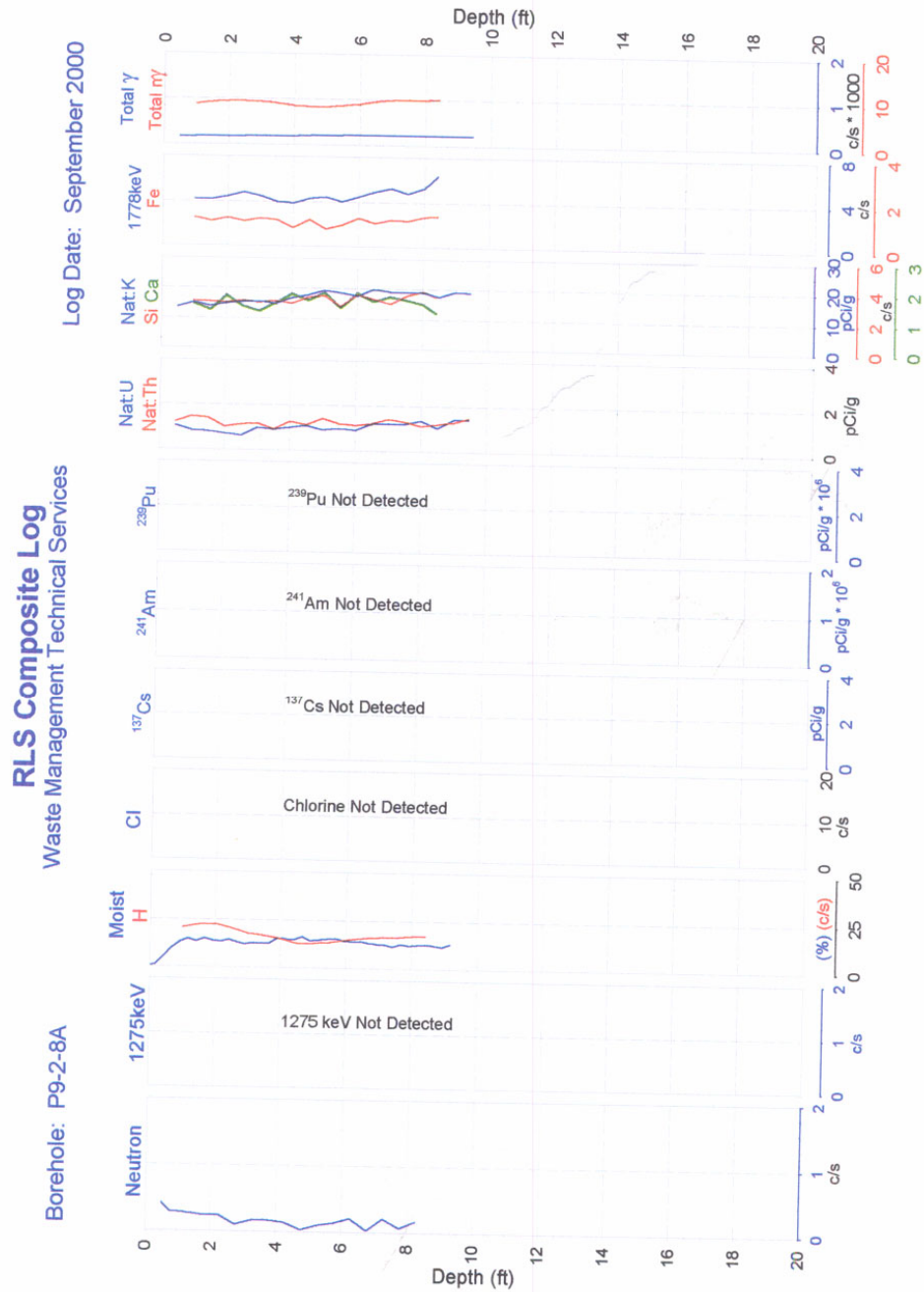


Figure 19 Composite Plot for Borehole P9-2-8A

6.8 Borehole P9-2-8A Survey Results

- Total casing depth is 9.77 ft.
- The waste zone depth interval is not clearly defined because no contaminants were identified in the borehole survey logs.
- Passive-neutron activity is highest near the surface.
- The neutron-moisture log shows little change at depths below 1 ft. The with an average apparent moisture content of 13.7 wt% from 1 to 9 ft.
- No Chlorine was detected.
- No Americium-241 or Plutonium-239 was detected.

Log Date: November 2000

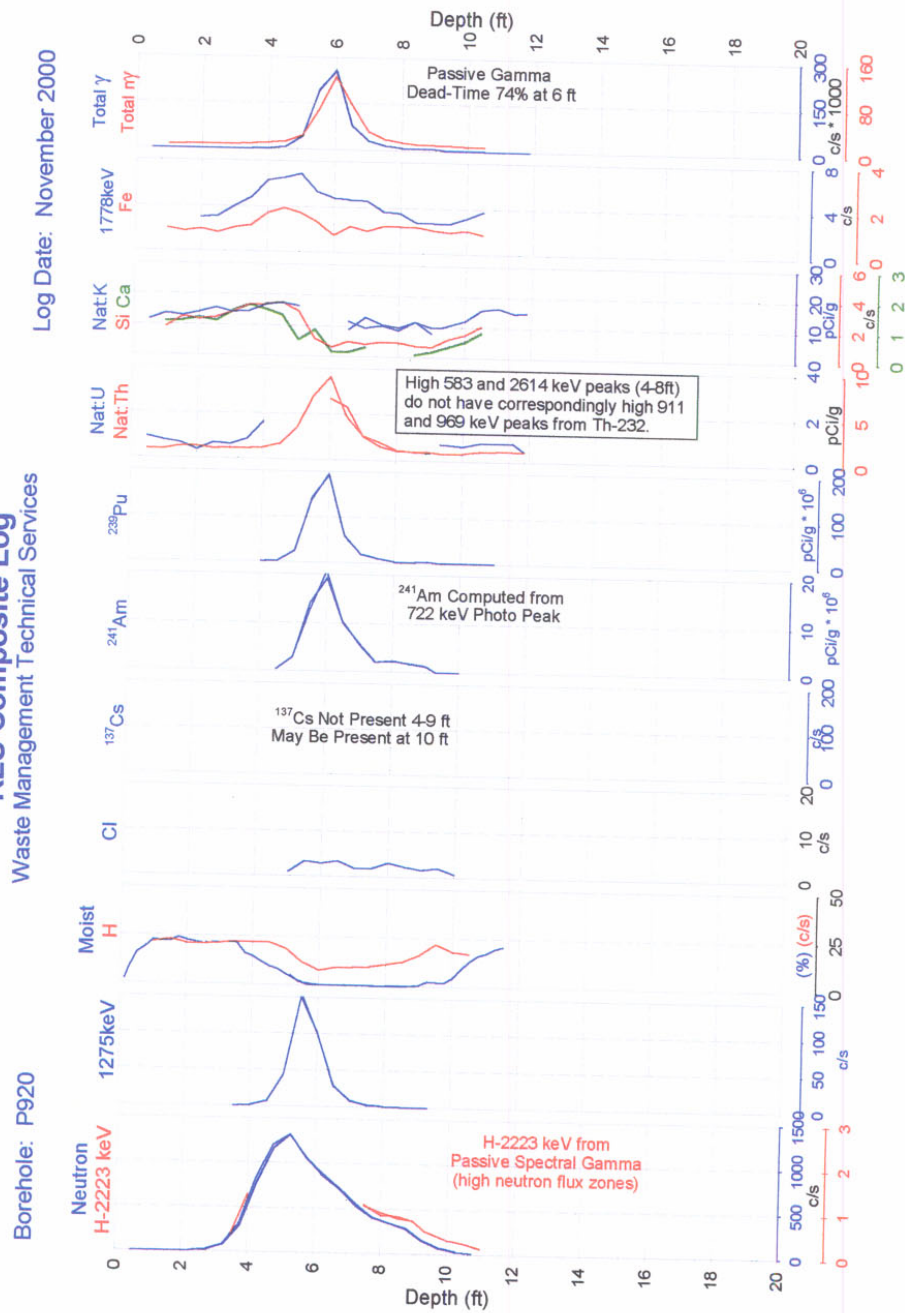


Figure 20 Composite Plot for Borehole P920

6.9 Borehole P920 Survey Results

- Total casing depth is 12.15 ft.
- This is a relog of the probe hole with highest concentrations of contaminants detected in the Pit-9 study area. The logging equipment has been modified to extend its linear response range. The maximum dead time of the spectral gamma probe during the relog survey of 74% did not exceed the linear limit of the logging system.
- The waste zone extends from 7 ft to 11 ft. Chlorine was detected at the maximum survey depth
- Passive-neutron detected elevated activity (up to 1.2 c/s) from 8 to 11 ft. The passive-neutron distribution profile is similar to the Pu-239 distribution.
- The hydrogen log increased slightly in the waste. The neutron-moisture log decreased in the waste zone to 1 wt% at 10 ft.
- Chlorine was detected between 7 ft and the maximum survey depth of 11.45 ft with a maximum activity of 1 c/s at 10 ft.
- Americium-241 was detected from 4 to 10 ft. Maximum concentration was 20,700 nCi/g at 6 ft. Concentration was computed from the 722 keV photo peak. Concentrations computed from 662 and 722 keV are the same within counting statistics, except for 10 ft, cesium-137 may be present at 10 ft.
- Plutonium-239 was detected from 9 to 12 ft at a maximum concentration of 130 nCi/g at 10 ft.
- Natural radionuclides: Potassium activity increases slightly in the over-burden (4 to 8 ft). Uranium and thorium show little change between the over-burden, waste, and under-burden zones, as is typical for the Pit 9 study area.
- Silicon, calcium responses decreased in the waste zone between depths of 8 and the maximum survey depth of 11.45 ft.
- Iron and the 1778 keV had two zones of increased response in the waste zone (8 and 10 ft).

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8.0 GLOSSARY

Activity	The rate of disintegration (transformation) or decay of radioactive material. The units of activity are the curie (Ci) and the becquerel (Bq).
Accuracy	The extent to which the results of a calculation or readings from an instrument approach the true values of calculated or measured quantities, and are free of errors.
Alpha particle	Two neutrons and two protons bound as a single particle that is emitted from the nucleus of certain radioactive isotopes in the process of decay or disintegration. Also, the nucleus of a helium atom which is ejected from some radionuclides during radioactive decay.
Alpha-n reaction	Reaction of an alpha particle with the nucleus of an atom that results in the production of a neutron and a transformed nucleus, i.e. an americium-beryllium (AmBe) neutron source.
Algorithm	A step-by-step procedure for solving a problem or accomplishing some task by a computer.
Angular dependence	Response of the detector as a function of the angle of incidence of the radiation being detected and a reference orientation.
Aspect ratio	The aspect ratio of slot or rectangular is the ratio of the width to the length of the opening.

Attenuation	Reduction of a quantity related to radiation, such as energy, fluence, etc., upon passage of radiation through matter, resulting from all types of interaction with matter.
Azimuth survey	Survey during which gamma radiation is measured with orientation to compass position via a collimated logging tool and tool orientation system.
Barns	A unit of area used in expressing a nuclear cross-section. 1 barn = 10^{-24} cm ² . Cross-sections per atom are customarily measured in barns.
Background radiation	Radiation from the natural environment including cosmic rays from space and radiation from naturally occurring radioactive elements in the air, in the earth, and in the body.
Beta particle	An elementary particle emitted from a nucleus during radioactive decay, having a single electrical charge and a mass equal to 1/1837 that of a proton. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron.
Bulk density	The density of rock as it occurs in nature.
Calibration	The process of determining the numerical relationship between the observed output of a measurement system and the value, based upon reference standards, of the characteristic being measured.
Casing	Metal pipe or tubing utilized to advance a borehole during drilling or used in the construction of wells.
Casing stickup	Extension above ground surface of a casing utilized for borehole or well drilling.
Collimator	A device used to limit the size, shape, and direction of the primary radiation beam. Any arrangement of slits or apertures which limits a stream of particles or photons to a beam in which all particles or photons move in the same (or nearly the same) direction.
CASASII	Computer Automated Spectral Acquisition System II (CASASII), computer program by Greenspan, Inc. for controlling the computer base logging system.
Compton scattering	Elastic scattering of photons (X rays or gamma rays) by electrons. In each such process the electron gains energy and recoils, and the photon loses energy. This is one of three ways photons lose energy upon interacting with matter, and is the usual method with photons of intermediate energy and materials of low atomic number.
Computer model	The simulation of a physical system by the use of a computer program (code) and a set of real world data.
Concentration	The quantity of radioactive material stated in terms of activity (or mass) per unit of volume or mass of a medium.

Confidence interval	The interval about an estimate of a stated quantity within which the expected value of the quantity is expected to be (with a specified probability). A measure of the reliability of a measurement. A 90% confidence interval means that 9 times out of 10 the measurement would be within the specified interval. Also designated 1-sigma (66 percent confidence interval), and 2-sigma (94 percent confidence interval). See uncertainty.
COC	Contaminants of concern.
Continuum	A sequence of values or elements varying by minute degrees, as in the background continuum observed in a spectrum.
Core data	Physical sample of formation material collected over a specified interval and representative of in-situ formation material.
Cosmic	High-energy subatomic particles and electromagnetic radiation from outer space that bombards the earth. Cosmic radiation is part of natural background radiation.
Cross-section	A measure of the probability that a nuclear reaction will occur. Usually measured in barns, it is the apparent (or effective) area presented by a target nucleus (or particle) to an oncoming particle or other nuclear radiation, such as a neutron or photon of gamma radiation.
Curie	A unit of radioactivity equal to 37 billion (3.7×10^{10}) nuclear transformations per second.
Daughter product(s)	Isotopes that are formed by the radioactive decay of some other isotope. In the case of ^{226}Ra , for example, there are 10 successive daughter products, ending in the stable isotope ^{206}Pb .
Dead-time correction	See Live Time.
Decay	The decrease in the amount of any radioactive material with the passage of time, as the result of the spontaneous emission from the atomic nuclei of nucleons or either alpha or beta particles, often accompanied by gamma radiation. When the radioactive material decays, the material may be converted to another radioactive species (decay product) or a non-radioactive material.
Dewar	Highly-insulated container for storing liquid nitrogen.
Diode	See semiconductor detector.
Doublet	Two closely spaced spectral lines (photo peaks).
Edge effects	The result of the presence of two adjoining yet different materials. As with a borehole logging probe, when the volume of material being

measured is less than the maximum investigation range of the logging probe.

Efficiency	Describes quantitatively the capability of a given detector to register radiation of a specific type. Several types of efficiency can be defined. <u>Counting (or overall) efficiency</u> : describes the probability for the detection of spontaneous nuclear decay processes of a specific single radionuclide by means of a given detector or detector-system arrangement plus associated instrumentation, and for a specific source geometry. It is the expectation value of the ratio of the number of detected events (recorded pulses) to the number of decay events, and thus relates the activity, A, of a radioactive source and the response of a radiation counting system (mean count rate, corrected for dead-time effects and background). <u>Individual (detection) efficiency</u> : probability for the detection of particles or photons of a specific energy or energy distribution for a given detector arrangement or counting geometry. It is the expectation value of the ratio of the number of detected events (recorded pulses) to the number of emissions. <u>Full-energy peak efficiency</u> : individual efficiency for a given gamma-ray energy related to the full-energy peak area in the pulse-height spectrum associated with energy-dispersive gamma-ray detection. <u>Partial (detection) efficiency</u> : individual efficiency where pulses from only part of the pulse-height spectrum are registered. <u>Intrinsic efficiency</u> : the probability of detecting a particle or photon incident on the detector. It is the expectation value of the ratio of the number of recorded pulses to the number of particles or quanta incident on the detector. <u>Total efficiency</u> : efficiency where any pulse, irrespective of its pulse height, is employed for registration.
Elastic scattering	Collisions in which the kinetic energy of neutron plus nucleus is unchanged by the collision, and the nucleus is left in the same state as before the collision.
Electron	Stable elementary particle with one negative elementary electric charge and a rest mass of approximately 9.10939×10^{-31} kg. Electrons surround the positively charged nucleus and determine the chemical properties of the atom. Positive electrons also exist.
Electron density	The number of electrons in a given volume.
Electron volt	[Abbreviation ev or eV] A unit of energy equivalent to the energy gained by an electron in passing through a potential difference of one volt; $1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$. Larger multiple units of the electron volt are frequently used: keV for thousand or kilo electron volts; MeV for million or mega-electron volts.
Element	One of the 103 known chemical substances that cannot be divided into simpler substances by chemical means. A substance whose atoms all have the same atomic number. Examples: hydrogen, lead, uranium.

Energy	Capacity for doing work. <u>Potential energy</u> : the energy inherent in a mass because of its special relation to other masses. <u>Kinetic energy</u> : the energy possessed by a mass because of its motion. <u>Binding energy</u> : the energy represented by the difference in mass between the sum of the component parts and the actual mass of the nucleus. <u>Excitation energy</u> : the energy required to change a system from its ground state to an excited state. Each different excited state has a different excitation energy. <u>Ionizing energy</u> : the average Energy lost by ionizing radiation in producing an ion pair in a gas. For air, it is about 33.73 eV. <u>Radiant energy</u> : the energy of electromagnetic radiation, such as radiowaves, visible light, x and gamma rays. <u>Reaction energy (nuclear)</u> : in the disintegration of a nucleus, it is equal to the sum of the kinetic or radiant energies of the reactants minus the sum of the kinetic or radiant energies of the products. If any product of a specified reaction is in an excited state, the energy of subsequently emitted gamma radiation is not included in the sum. The "ground-state nuclear reaction energy" is the reaction energy when all reactant and product nuclei are in their ground states.
Energy calibration	The relationship between the height of the amplifier output pulse and the energy of the photon originating in the radioactive source.
Epi-thermal	A neutron having an energy in the range immediately above the thermal range, roughly between 0.02 and 100 electron volts.
Equilibrium	A state of balance or rest. Radioactive equilibrium is the state in which the rate of formation of atoms is equal to the rate of their disintegration by radioactive decay, so that the amount of the element or isotope is constant. In a radioactive series, the state which prevails when the ratios between the amounts of successive members of the series remains constant.
Ex-Situ	Removed from the natural position.
Fast neutron	Neutrons with energies above about 10 keV.
Fission	The division of a heavy nucleus into two (or, rarely, more) parts with masses of equal order of magnitude, usually accompanied by the emission of neutrons, gamma radiation, and, rarely, small charged fission fragments.
Fission products	Any radionuclide or stable nuclide resulting from nuclear fission, including both primary fission fragments and their radioactive decay products.
Flux	A rate of flow across a unit area. For example, a neutron flux is the number of neutrons that cross 1 cm ² /sec.
Frequency	Number of cycles, revolutions, or vibrations in a unit of time.
FWHM	The full width of a gamma-ray peak distribution measured at half the maximum ordinate above the continuum.

Functional form	A mathematical function having characteristic features.
Gain	The ratio of increase of output over the input in an amplifier. Factor by which a pulse is amplified. Increasing the gain by a factor of 2, increases the amplitude of the pulse by a factor of 2.
Gain conversion	The maximum number of channels a pulse can digitize to.
Gain drift	The variance in the energy to channel reference that is established at the beginning of logging and monitored throughout a survey.
Gamma ray,	High-energy, short-wavelength electromagnetic radiation (range of energy, 10 keV to 9 MeV). Gamma radiation frequently accompanies alpha and beta emissions and always accompanies fission. Gamma rays are very penetrating and are best stopped or shielded by dense materials, such as lead or depleted uranium. Gamma rays are essentially similar to x-rays, but are usually more energetic, and are nuclear in origin.
Gamma radiation	Electromagnetic radiation emitted in the process of nuclear transition or particle annihilation. See "gamma ray" above.
Gaussian	Set of data having the shape of a normal distribution; pertaining to Gaussian or normal curve.
Geometry	In nuclear physics measurements, an arrangement of source and detecting equipment.
Gravimetric	Pertaining to measurement by weight.
Grout	Mixture of water and cement or other chemical that solidify upon drying that is used for filling voids between casing strings or between the casing and formation.
Half-life	The length of time during which a radioactive substance will lose one half of its radioactivity by decay. Each radionuclide has a unique half-life. Half -lives range from fractions of seconds to billions of years.
HPGe	High Purity Germanium; solid state high resolution spectral-gamma ray detector that must be operated at liquid nitrogen temperatures.
Inelastic collision	Collision in which at least one system gains internal excitation energy at the expense of the total kinetic energy.
Inelastic scattering	Scattering collision of neutron with attendant loss of kinetic energy which causes excitation of the target nucleus, and subsequent release of gamma rays.
INEEL	Idaho National Engineering and Environmental Laboratory.
In-Situ	In the natural or original position.

Intensity	The energy or the number of photons or particles of any radiation incident upon a unit area or flowing through a unit of solid material per unit of time. In connection with radioactivity, the number of atoms disintegrating per unit of time.
Isotopes	Different forms of the same chemical element that are distinguished by different numbers of neutrons in the nucleus. A single element may have many isotopes, and some may be radioactive and some may be stable.
KeV	Symbol for thousand electron volts. (See electron volt).
KUT	The naturally occurring radionuclides (Potassium ⁴⁰ K; Uranium ²³⁸ U ²³⁵ U; and Thorium ²³² Th).
Live Time	Live Time = Real Time – Dead-time; where Real Time is the elapsed wall clock time; Live Time is the elapsed time the system was available to process detector pulses; Dead-time is the elapsed time the system was processing detector responses.
LMITCO	Lockheed Martin Technologies Company.
MCA	Multi Channel Analyzer, electronic hardware instrumentation used to acquire energy spectra from the borehole logging probes.
Mean	Arithmetic mean or average on numerical values as computed by the sum of the values divided by the number of values.
Median	A value in an ordered set of values below and above which there is an equal number of values.
MeV	Symbol for million electron volts. (See electron volt).
Millicurie	One thousandth (10 ⁻³) of a curie (mCi).
Microcurie	One millionth (10 ⁻⁶) of a curie (μCi).
MDL	Minimum Detection Level for a specific radionuclide under specific logging conditions (i.e., detector efficiency, counting time, gamma ray energy, casing thickness, water inside the borehole, and compton background level from other radionuclides present in the formation soils).
Mode	The most frequent value of a set of data.
Model	A mathematical or physical system, obeying certain specified conditions, whose behavior is used to understand a physical, biological, or other system to which it is analogous in some respect. A physical or mathematical representation of reality.
Monte Carlo model	A method permitting the solution by means of a computer of problems of physics, such as those of neutron transport, by determining the

history of a large number of elementary events by the application of the mathematical theory of random variables.

MCA	Multi-channel analyzer.
Multiplet	A set of overlapped peaks.
N-Gamma	Neutron-capture / spectral-gamma borehole logging tool.
Nanocurie	One billionth (10^{-9}) of a curie (nCi).
Naturally occurring	Occurring naturally in the soil. Not caused by industrial or other human activity.
Neutron	An elementary nuclear particle with a mass approximately the same as that of a hydrogen atom and electrically neutral; its mass is 1.008982 mass units. Neutrons are commonly divided into subclassifications according to their energies as follows: thermal, around 0.025 eV; epithermal, 0.1 to 100 eV; slow, less than 100 eV; intermediate, 102 eV; fast, greater than 0.1 MeV.
Neutron absorbers	Elements with a high thermal neutron capture cross-section. Material with which neutrons interact significantly by reactions resulting in their disappearance as free particles.
Neutron capture	The process in which an atomic nucleus absorbs or captures a neutron. The probability that a given material will capture neutrons is measured by its neutron capture cross-section, which depends on the energy of the neutrons and on the nature of the material.
Neutron capture cross-section	See capture cross-section.
Neutron density	The number of free neutrons per unit volume. Partial densities may be defined for neutrons characterized by such parameters as energy and direction.
Neutron flux	A measure of the intensity of neutron radiation. It is the number of neutrons passing through 1 square centimeter of a given target in 1 second. Expressed as nv , where n = the number of neutrons per cubic centimeter and v = their velocity in centimeters per second.
NIST	National Institute of Standards and Testing.
Non-Detect Limit	The MDL for a radionuclide under the same logging conditions except that the formation soils contain only the natural radionuclides (KUT) at average concentration levels for the zone of interest. No man-made radionuclides are detected.
Normalize	To adjust the representation of a quantity so that this representation lies within a prescribed range, or from a common datum.

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OEM	Operating Environmental Monitoring procedures outlining the basis and scope for environmental monitoring conducted WMTS.
Overburden	Clean soil overlaying the waste discarded within the pit.
PNNL	Pacific Northwest National Laboratory.
Photo peak	Elevated counts in MCA channels that correspond to unattenuated discrete gamma ray energies from of radio-isotope decay.
Picocurie	One one-trillionth (10^{-12}) of a curie (pCi).
PCB	Polychlorinated biphenyl.
Precision	The ability of an instrument to reproduce a given measurement; therefore, the variance observed for a given repeat sequence is used to determine the system or equipment precision.
Probability	The statistical likelihood that a given event will occur within a given period.
PHA	Pulse height analysis. Analysis of spectral data via graphical representation of the emitted energy (pulse height) versus the number of events (counts) as a function of energy.
Radiation	The energy emitted in the form of photons or particles as those emitted from a decaying atom.
RWMC	Radioactive Waste Management Complex.
Radionuclide	A species of atoms having a particular number of protons (Z), a particular number of neutrons (A), and a particular atomic weight ($N = Z + A$) that emit radiation.
ROD	Record of Decision.
RFP	Rocky Flats Plant.
Semiconductor detector	A particle detector which detects ionization produced by energetic charged particles in the depletion layer in a semiconductor (usually a very pure single crystal of silicon or germanium).
Slow neutrons	Neutrons with energies of about 1 eV to a few hundred keV.
Spectra	A spectra is generated by tallying detector signal pulses into MCA channels that correspond to the voltage level of the signal pulse. A spectra reflects the flux distribution present at a particular detector position in the borehole and is depicted as a graph with the MCA channels represented on the x axis and the number of counts in each channel along the y axis.

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Spectra background	The average counts in MCA channels immediately above and below a photo peak that correspond to the background flux of attenuated gamma rays, compton scattering.
Spectroscopy	The branch of physics concerned with the production, measurement, and interpretation of electromagnetic spectra arising from either emission or absorption of radiant energy by various substances.
Standard deviation	The amount that the data deviate from the mean. Defined as the square root of the sample variance.
SDA	Subsurface Disposal Area.
Thermal neutron	A neutron in thermal equilibrium with its surrounding medium. Thermal neutrons are those that have been slowed down by a moderator to an average speed of about 2200 meters per second (at room temperature) from the much higher initial speeds they had when expelled by fission. All neutrons with energies less than about 1 eV are termed "thermal", the average energy at 72-deg F is 0.025 eV.
Total casing depth	The maximum depth, below ground surface, to which casing has penetrated during borehole or well drilling.
Transformation	The process of radioactive decay in which one radionuclide is transformed into another.
TRU	Transuranic element. An element above uranium in the Periodic Table, that is, with an atomic number greater than 92. All 11 transuranic elements are produced artificially and are radioactive. They are neptunium, plutonium, americium, curium, berkelium, californium, einsteinium, fermium, mendelevium, nobelium, and lawrencium.
Uncertainty	A measure of how much confidence one has in the accuracy of a measurement. Both random fluctuations, associated with statistical variations inherent to the measurement process, and systematic errors commonly associated with technique or judgment, may contribute to uncertainty. Also expressed as 1-sigma, 2-sigma, etc. (see confidence).
Underburden	The soil material below the waste within the pit.
US-DOE	United States Department of Energy.
WMNW	Waste Management Federal Services, Inc., Northwest Operations, predecessor of Waste Management Technical Services.
WMTS	Waste Management Technical Services, a subsidiary of GTS Duratek.
Waste seam	The zone where waste was deposited and subsequently covered or buried by clean soil which is referred to as "overburden". The "underburden" is soil material below the waste.

Water table

Undisturbed upper surface of the saturated zone. The pressure everywhere on this surface is at atmospheric pressure.

Z/A ratio

The ratio of the atomic number (number of protons) of an element (Z) to its atomic mass (number of protons and neutrons) (A).